Use of a Chlorophyll Meter to Monitor Nitrogen Status and Schedule Fertigation for Corn

T. M. Blackmer and J. S. Schepers

Research Question

Corn production may lead to groundwater contamination by nitrate when N fertilizers are applied in excess of the crop's needs. Practices that will synchronize N fertilization with the crop's needs could help reduce the potential for groundwater contamination by nitrate without reducing yields.

Literature Summary

Monitoring leaf N concentration provides a means of identifying crop N status, but correlation of this measurement to grain yield is confounded by luxury consumption and requires time consuming lab analysis. Leaf chlorophyll measurements can also detect N deficiencies, but are not as sensitive to luxury consumption as other N measurements. The SPAD 502 chlorophyll meter provides an instantaneous means of evaluating chlorophyll content.

Applied Questions

Could the chlorophyll meter detect N deficiencies that resulted in reduced grain yields?

The chlorophyll meter, when used with a reference strip (an area receiving adequate N), accurately detected N deficiencies that resulted in reduced grain yields. Using chlorophyll meter readings without an in-field reference strip resulted in variability from such factors as different hybrids, soil types, and growth stage.

Did all sites have the same pattern of N availability over the season?

All sites responded differently. Some sites became more N deficient as the season progressed. In others, more N became available as the season progressed. Nitrogen availability at one site remained constant over the season. This variability may apply only to irrigated sites in the area studied.

Could deficiencies detected by the chlorophyll meter be corrected soon enough to prevent yield loss?

Treatments that started with adequate fertilizer and then became deficient were corrected without yield loss. Young plants in a deficient state could not be corrected to full yield potential.

Full scientific article from which this summary was written begins on page 56 of this issue.

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T.M. Blackmer* and J.S. Schepers

The SPAD 502 chlorophyll meter[1] (Minolta Camera Co., Osaka, Japan) is a new instrument that has been introduced as a tool to improve N management. This study was conducted to evaluate the ability of the chlorophyll meter to detect plant N deficiencies in corn (*Zea mays* L.) by identifying when it would be appropriate to supply N fertilizer in irrigation water. Nitrogen response studies were conducted on five irrigated sites in central Nebraska in 1991. Crop N status was monitored during the growing season and additional N was added to simulate fertigation when apparent N deficiencies were detected with the meter. Changes in N status over the season were determined relative to an adequately fertilized in-field reference plot. Early-season (V6) N deficiencies were poorly correlated with yield because factors such as nitrate leaching, organic matter mineralization, and nitrate present in irrigation water modified the crop N supply during the growing season. Nitrogen deficiencies detected late (R4–R5) in the season were more highly correlated with yield than early season N stresses. Treatments that started with adequate fertilizer and then became deficient were corrected without yield loss. Young plants in a deficient state could not be corrected to full yield potential. Chlorophyll meters can be a valuable tool for N management of irrigated corn production when used to assess crop N status in the irrigated Great Plains.

Leaf N concentration at silking has been shown to be highly correlated with grain yield in corn (Tyner and Webb, 1946). Chlorophyll concentration (leaf greenness) in corn has been found to be positively correlated with leaf N concentration (Wolfe et al., 1988; Lohry, 1989; Wood et al., 1992) and N sufficiency (Zelich, 1982; Girardin et al., 1985; and Lohry, 1989). It follows that leaf chlorophyll concentration reflects relative crop N status and yield level. The SPAD 502 chlorophyll meter provides a convenient means of assessing relative leaf chlorophyll concentration and therefore offers a promising tool for evaluating the N status of corn during the growing season. To measure relative chlorophyll concentration, the meter is clamped on the corn leaf and light transmittance through the leaf is determined at 650 and 940 nm. The transmittance at 940 nm is used as a reference to compensate for factors such as leaf moisture content and thickness while the 650 nm source is sensitive to chlorophyll concentration. Chlorophyll meter readings provide a relative indication of leaf chlorophyll concentration (Yadava, 1986; Marquard and Tipton, 1987; Dwyer et al., 1991).

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Excessive levels of available N can result in luxury consumption, but usually do not increase the meter readings (Schepers et al., 1992a). The plateau in chlorophyll meter readings at high fertilizer N rates is thought to reflect the fact that nutrients other than N are limiting chlorophyll production. As such, luxury consumption is not detected by the meter, which makes it ideal for detecting an N deficiency. Plants treated the same except for N availability should show differences only if an N deficiency exists. Because chlorophyll meters are not sensitive to luxury consumption, one need not know the exact level of N required for maximum yield as long as a slight excess is maintained in a reference area of the field. Well fertilized reference areas can be established within a field and weekly comparisons of chlorophyll meter readings can be made to determine if deficiencies are present. If a deficiency is detected, fertilizer can be applied with the irrigation water. This strategy permits fertilizer to be applied only when needed. This N management approach accounts for fluctuations in seasonal N availability resulting from parameters difficult to estimate before the growing season, such as N mineralization or leaching losses. For this strategy to be practical, however, deficiencies must be detected early enough to be corrected by supplemental fertilizer N before the yield potential declines.

The use of chlorophyll meters offers several advantages over conventional tissue testing procedures for detecting N deficiencies. The most obvious advantages are portability and rapid assessment of N status in the field without destroying plant tissue. In a practical sense, chlorophyll meters have been shown to be an effective tool for identifying sites that are responsive and nonresponsive to sidedressed N (Piekielek and Fox, 1992). Chlorophyll meters have also been shown to effectively quantify N status during the reproductive stages of corn growth (Schepers et al., 1992b; Wood et al., 1992). These observations raise the possibility of using this tool to identify sites that would be responsive to N fertilizers and where N could be injected into irrigation water during the growing season to correct an N deficiency. Such use of the meter offers potential economic and environmental advantages because it enables producers to reduce rates of insurance N with minimal risk of yield reduction. However, the conceptual use of chlorophyll meters presented above has not been evaluated under field conditions. The objective of this report is to evaluate the chlorophyll meter as a tool for detecting N deficiencies and scheduling N fertilization during the growing season of irrigated corn.

[1] Mention of trade names or proprietary products does not indicate endorsements by USDA, and does not imply its approval to the exclusion of other products that may also be suitable.

Table 1. Site description for N fertilizer response trials conducted in central Nebraska.

Site	Soil type	Water nitrate-N	Previous crop	Residual N†	Hybrid‡	Initial N rate	Fertigations§	
		ppm		lb N/acre		lb N/acre	no.	lb N/acre
1	Leshara silt loam (fine-silty, mixed, mesic Typic Haplaquolls)	2	Sweetclover [*Melliotus officinalis* (L.) Lam.]	65.1	3394	0	4	120
						40	3	90
						80	1	30
						120		
						160		
						200		
2	Wood River silt loam, (fine, montmorillonitic, mesic Typic Natrustolls)	1	Soybeans [*Glycine max* (L.) Merr.]	52.2	3417	0	4	120
						40	3	90
						80	2	60
						120	1	30
						160		
3	Hord silt loam (fine-silty, mixed, mesic Cumulic Haplaquolls)	17	Corn (*Zea mays* L.)	47.4	3162	0	2	60
						40	1	30
						80		
						120		
						160		
4	Hord silt loam	6	Sorghum [*Sorghum bicolor* (L.) Moench]	26.2	Unknown	0	1	30
						40		
						80		
						120		
						160		
5	Hord silt loam	31	Corn	49.0	3379	0	2	60
						40	1	30
						80		
						120		
						160		

† Calculated from available N (ammonium and nitrate) present in the top 24 in. of soil.
‡ Pioneer brand hybrid.
§ Fertigation applied rates of 30 lb N/acre, and values in parenthesis represent the total N applied.

MATERIALS AND METHODS

This study was conducted on five N-response irrigated corn sites in central Nebraska (Table 1). Preliminary residual soil samples were collected by gathering 16 cores (0.70 in. diameter, to a depth of 24 in.) with a hand probe. The samples were oven dried, ground to pass a 14 mesh sieve, and extracted using 2 N KCl. Nitrate and ammonium-N concentrations were determined using a Lachat flow-injection analyzer (Lachat Instruments, Mequon, WI). At each location, plots were either 30 by 40 ft (12 rows, 30-in. spacings) or 48 by 40 ft (16 rows, 36-in. spacing) arranged in randomized complete-block designs with four replications. Each study was planted with a different corn variety between 21 Apr. and 14 May 1991. Ammonium nitrate fertilizer was broadcast at various initial N rates (Table 1) and incorporated with a rototiller shortly after planting. At sites 1, 2, 3, and 4, soils were cultivated to form furrows for irrigation before the corn was 18 in. tall. Site 5 required no furrows because irrigation was applied with a sprinkler system. Other than fertilizer application and grain harvest, all plots were managed using practices common to corn production in the Central Platte River Valley.

To monitor the N status of the crop, N sufficiency indexes were calculated as the ratio of chlorophyll meter readings for the treatment receiving lower amounts of N fertilizer (all treatments except the highest N rates) to the treatment receiving the highest amount of N (the reference area).

Chlorophyll meter readings were collected using the SPAD 502 at approximately weekly intervals during the growing season. Prior to silking, readings were collected from the most recent fully expanded leaf (i.e., the most recent fully collared leaf). First readings were collected when corn plants were at V6 (12 in. tall), as discussed by Ritchie et al. (1992). Measurements were taken midway between the stalk and the tip of the leaf, and midway between the margin and the mid-rib of the leaf from 30 representative plants randomly selected from the center two rows of each plot. Plants unusually close together or far apart, or those that were damaged were not sampled. After silking, readings were taken using similar methods, except the ear leaf was sampled. Chlorophyll meter data were collected until leaf senescence increased plant-to-plant variability (approximately R5).

Table 2. Linear regression parameters for relationships between grain yields and chlorophyll meter readings.

Site	V-6 stage			R4-R5 stage		
	Intercept	Slope	r^2	Intercept	Slope	r^2
1	−46.0	5.5	0.48	−53.3	4.8	0.88
2	−2.6	2.9	0.06	64.1	1.6	0.89
3	29.8	4.6	0.67	−87.2	5.4	0.89
4	−835.9	25.6	0.31	4.9	2.0	0.79
5	139.6	0.8	0.55	5.6	3.1	0.55
Combined	−25.9	4.3	0.25	−155.4	6.3	0.84

Treatments were characterized as N deficient at the site when the sufficiency index was <0.95 for two successive weeks. When such deficiencies were detected, the plots were split and N was applied to one of the subplots to simulate fertigation. Nitrogen was applied to the split plots as ammonium nitrate (dissolved in water) at a rate of 30 lb N/acre (a typical rate of N that could be applied through irrigation systems without injuring corn plants). These fertilizer applications were then incorporated with typical irrigation for the site.

The center two rows of each plot were hand harvested using 20-ft segments from each plot. A mechanical sheller

Table 3. Fertilizer rate comparisons that resulted in differences in R-5 stage chlorophyll meter readings and corresponding N fertilizer effects on grain yield. Comparisons include only nonfertigated treatments.†

Site	Comparison‡	Probability of a greater F value	
		For yield	For chlorophyll meter
1	0 vs. 80	0.006	0.039
1	0 vs. 120	0.004	0.016
1	0 vs. 160	0.011	0.011
1	0 vs. 200	0.002	0.006
1	40 vs. 120	0.049	0.050
1	40 vs. 160	0.126	0.019
1	40 vs. 200	0.026	0.034
2	0 vs. 40	0.267	0.017
2	0 vs. 80	0.075	0.002
2	0 vs. 120	0.014	0.001
2	0 vs. 160	0.008	0.001
2	40 vs. 120	0.064	0.038
2	40 vs. 160	0.114	0.002
2	80 vs. 160	0.236	0.013
3	0 vs. 120	0.138	0.044
3	40 vs. 120	0.171	0.015
4	0 vs. 40	0.226	0.044
4	0 vs. 80	0.090	0.001
4	0 vs. 120	0.428	0.009
4	0 vs. 160	0.223	0.003

† Fertigation treatments were not significantly different than the reference plots.
‡ Initial N treatments in lb N/acre.

was used to separate the grain from the cob. Grain yields were adjusted to 15.5% moisture content.

The regression analyses (Table 2) were performed on the relationship between grain yields and chlorophyll meter readings at the V6 growth stage and the R4–R5 growth stage. To detect treatment differences for Table 3, Fisher's LSD approach was used on the nonfertigated plots. All comparisons found statistically different ($P < 0.05$) for either the grain yield parameter or the chlorophyll meter parameter at the R4 to R5 stage are reported. Analysis of variance was used to determine grain yield response to N.

RESULTS AND DISCUSSION

Corn grain yields observed for the highest N rates ranged from 72 to 225 bu/acre (Fig. 1). Analysis of variance showed a significant ($P < 0.05$) effect of N rate at sites 1 and 2 only. Relatively low yields at site 4 may have been caused by an extreme N deficiency early in the season. This site had been depleted of N by previous cropping without fertilization as reflected by low residual N in the soil (Table 1). No starter fertilizer was applied at site 4 and wet weather caused a delay in application of the initial N treatments until the plants were about 4-in. tall.

Relationships between grain yields and chlorophyll meter readings taken when the corn plants were at V6 showed a trend for increased yields as chlorophyll meter readings increased within locations, but variation among locations resulted in poor predictability (Fig. 2). When data from all sites were combined, the relationships between chlorophyll meter readings and grain yields had poor predictability, even though it was statistically significant ($r^2 = 0.25$, $P < 0.01$). Poor relationships (poor predictability) at V6 were also observed when data from several of the individual sites were analyzed separately (Table 2). These observations indicate that, early in the season, chlorophyll meters have limited potential as a general tool for predicting yield responses to N fertilizer unless the readings can be adjusted to account for other environmental differences.

Relationships between grain yields and chlorophyll meter readings at R4 (dough stage) or R5 (dent stage) were better than V6 relationships both within and across locations (Fig. 3). When data from all sites were combined, a statistically significant linear correlation ($r^2 = 0.84$, P

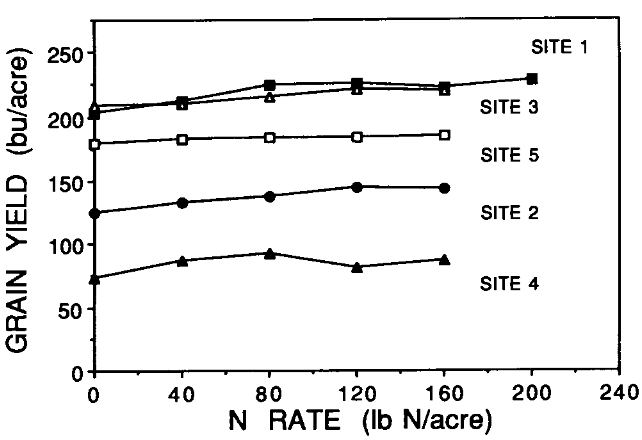

Fig. 1. Corn grain yield responses to initial fertilizer N rates at five sites.

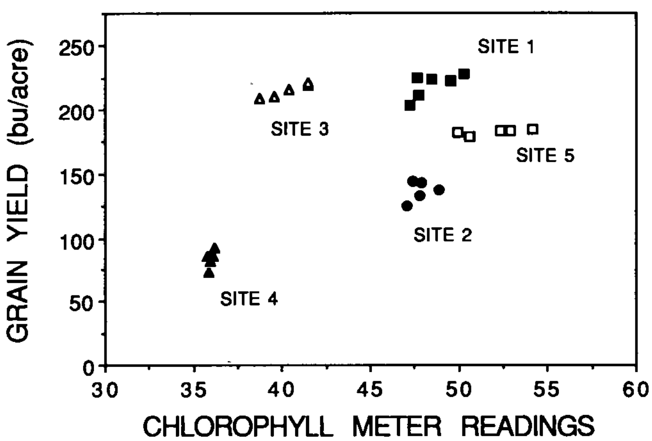

Fig. 2. Relationships between corn grain yields and early season chlorophyll meter readings at the V6 growth stage.

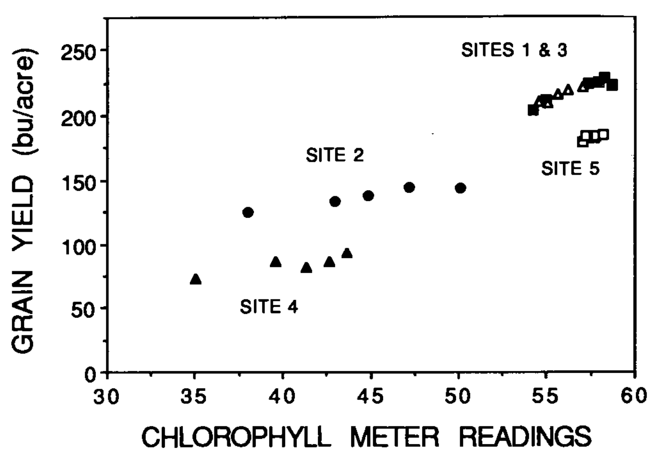

Fig. 3. Relationships between corn grain yields and late season chlorophyll meter readings at R4–R5 growth stage.

< 0.001) between chlorophyll meter readings and grain yields was observed. The practical significance of this relationship for diagnosing N deficiencies is questionable, however, because the trend was largely related to differences between sites instead of differences due to N applied within sites. The overall trend shown in Fig. 3 was caused by differences in leaf greenness related to factors such as hybrids, rotation, and locations rather than N status. These observations indicate that chlorophyll meter use in midseason probably has limited potential as a tool for predicting yield responses to N fertilizer unless the readings are interpreted for a specific location.

Seasonal trends in N sufficiency indexes observed on unfertilized plots were different at each site (solid circles) in Fig. 4. The severity of N deficiency tended to decrease with time at sites 3 and 5, but tended to increase with time at sites 2 and 4. Increasing N deficiency over the season could be explained by depletion of available N as a result of plant uptake and low N content in irrigation water. Situations showing increasing N sufficiency over time could be explained by mineralization of available N from organic matter, more extensive extraction of N from volumes of soils containing available N, or availability of nitrate in irrigation water. Nitrates in irrigation water offer a reasonable explanation for the correction of deficiencies at sites 3 and 5 because large amounts of nitrate were contained in the water (Table 1). The failure of nitrate in irrigation water to correct deficiencies at site 4 may be explained by visual observations of poor early season root development and lower levels of residual N resulting in a visual early season N deficiency that lowered the yield potential. Grain N concentrations for this site were high for the higher N treatments suggesting that N availability was not a problem (data not presented).

Seasonal trends in N sufficiency indexes illustrated in Fig. 4 help to explain why late-season chlorophyll meter readings resulted in better relationships with grain yields than did early season chlorophyll meter readings (Table 2). The lack of relationship between grain yields and early-season chlorophyll meter readings at site 2, for example, should be expected because yield differences were caused by deficiencies that developed later in the season. The lack of a significant relationship between early season meter readings and grain yield at site 5 resulted from an N deficiency observed early in the season that was apparently corrected by nitrate present in the irrigation water or N supplied by mineralization.

Leaf greenness can be influenced by a number of factors (e.g., hybrid, stage of growth, and some nutrients), but soil N availability probably has the greatest effect within a field. Changes in N sufficiency indexes throughout the growing season reflect the initial N status of the soil and N additions from various sources (Fig. 4). Because fertigation treatments were applied only when deficiencies were detected, the number of fertigated plots varied among the sites. In general, plots receiving lower fertilizer application rates at planting required more fertigation, while sites with greater N fertilizer inputs and N from irrigation water (sites 3 and 5) required less fertigation (Table 1). Situations with low concentrations of nitrate in the water or a high leaching potential had the greatest need for fertigation (site 2). Prescribed fertigation treatments were able to maintain minimal N deficiencies as indicated by the sufficiency index (Fig. 4).

Evidence that the chlorophyll meter had adequate sensitivity to detect N deficiencies that could significantly reduce yields is provided in Table 3. This table contains only comparisons between fertilizer N rates that were significantly different for either yield or chlorophyll meter readings at the R5 growth stage. Results show that eight grain yield comparisons and 20 chlorophyll meter reading comparisons were statistically different. Each of the eight cases that was statistically different for yield was also statistically different for chlorophyll meter reading comparisons. This concurrence of observations is a strong indicator that the chlorophyll meter can detect N deficiencies that could result in yield reductions.

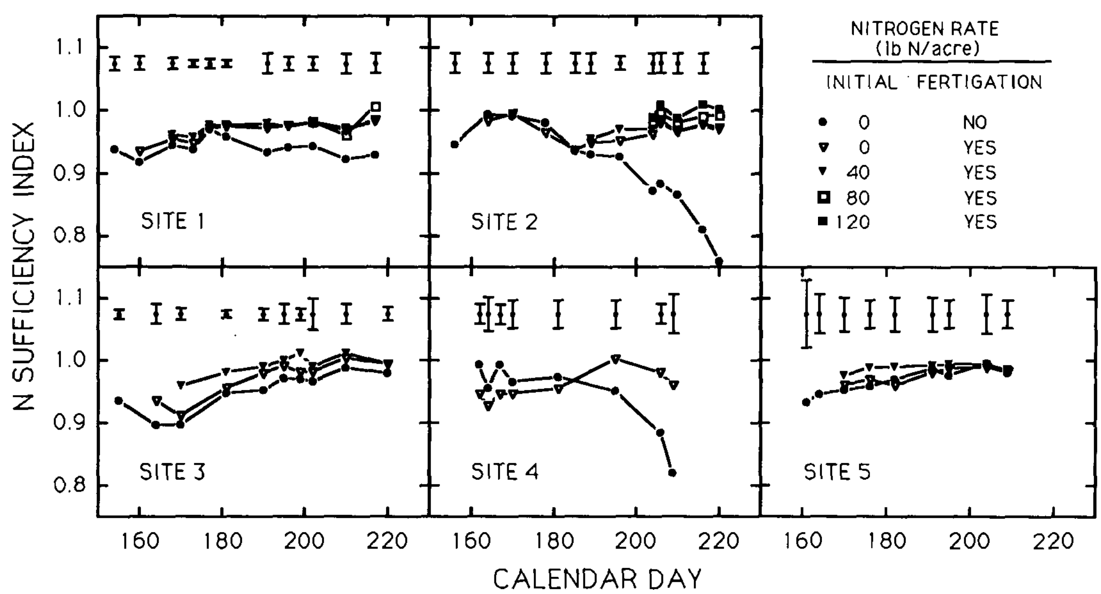

Fig. 4. Nitrogen sufficiency indexes for plots receiving various combinations of initial N rates and fertigation treatments.

Reasons for the greater number of significant comparisons with the chlorophyll meter than with yield could be a result of at least two factors. First, a higher variance for the yield measurements than for the chlorophyll meter readings could result in detecting fewer yield comparisons that were truly different (type II error) from chlorophyll meter readings. When using the chlorophyll meter, damaged plants were not sampled and the same number of plants (30) were always sampled for each plot. In contrast, yield measurements were made on an area basis. Yield variability is inevitable because damaged plants were included in the measurements, and plant stands may vary from plot to plot. This leads to the potential for greater variability for yield data than from chlorophyll meter measurements.

Secondly, the detection of luxury consumption by the meter could result in more significant comparisons for the chlorophyll meter readings than grain yield. However, because the chlorophyll meter was able to detect differences between 0 and 80 lb N/acre, but usually was not able to detect differences between 80 and 160 lb N/acre, suggests that luxury consumption does not present a problem when interpreting the data. If luxury consumption was a significant problem, we would expect more significant comparisons involving higher N rates.

Neither the chlorophyll meter nor yield response measurements were able to detect differences between the highest initial N treatments (adequately fertilized) and the fertigation treatments (Table 3). This observation presents preliminary evidence that use of the chlorophyll meter is an effective way to schedule fertigation in the irrigated Great Plains Region.

CONCLUSIONS

Chlorophyll meters were able to distinguish between fertilizer N treatments that resulted in N deficiencies that reduced corn grain yields. Chlorophyll meter data followed trends similar to grain yield. Calculating an N sufficiency index relative to chlorophyll meter readings from a non-N-limited area made it possible to compare crop N status across fields, hybrids, and sampling dates. The ability of the chlorophyll meter to schedule fertigation is promising because it offers the possibility of conserving fertilizer and protecting the environment. More research is needed to identify the best N sufficiency index to initiate fertigation and to determine if this strategy has application outside of the Great Plains.

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